AIP | Proceedings

COMPARISON OF THEORY AND MEASUREMENTS OF A TWO-STAGE LIGHT-GAS GUN

S. Levinson, D. Berry, B. Pedersen, and S. Bless

Citation: AIP Conference Proceedings **1195**, 623 (2009); doi: 10.1063/1.3295216
View online: http://dx.doi.org/10.1063/1.3295216
View Table of Contents:
http://scitation.aip.org/content/aip/proceeding/aipcp/1195?ver=pdfcov
Published by the AIP Publishing

Articles you may be interested in
Diagnostic system to measure spatial and temporal profiles of shock front using compact two-stage light-gas gun and line reflection method
Rev. Sci. Instrum. **78**, 043904 (2007); 10.1063/1.2723751

PVDF Gauge Piezoelectric Response under Two-Stage Light Gas Gun Impact Loading
AIP Conf. Proc. **620**, 1149 (2002); 10.1063/1.1483741

Optimization of a compact two-stage light-gas gun aiming at a velocity of 9 km/s
Rev. Sci. Instrum. **72**, 4270 (2001); 10.1063/1.1406924

Enhanced performance of a two-stage, light-gas gun
AIP Conf. Proc. **78**, 184 (1982); 10.1063/1.33356

Flash x-ray tube for diffraction studies on a two-stage light-gas gun
Rev. Sci. Instrum. **51**, 741 (1980); 10.1063/1.1136306

This article is copyrighted as indicated in the article. Reuse of AIP content is subject to the terms at: http://scitation.aip.org/termsconditions. Downloaded to IP: 128.83.205.78 On: Mon, 23 Mar 2015 21:43:31

CP1195, *Shock Compression of Condensed Matter - 2009*,
edited by M. L. Elert, W. T. Buttler, M. D. Furnish, W. W. Anderson, and W. G. Proud
© 2009 American Institute of Physics 978-0-7354-0732-9/09/$25.00

COMPARISON OF THEORY AND MEASUREMENTS OF A TWO-STAGE LIGHT-GAS GUN

S. Levinson, D. Berry, B. Pedersen, and S. Bless

University of Texas at Austin, Institute for Advanced Technology
3925 W. Braker Lane, Suite 400 • Austin TX 78759-5316

Abstract. A comparison of techniques for obtaining projectile velocity history on a two-stage launcher and discuss gun code accuracy vis-à-vis pressure gauges and the new photonic Doppler velocimetry (PDV) technique is presented. The PDV technique itself is described in a companion paper. The PDV records were differentiated to compute acceleration and, hence, base pressure. Two acceleration episodes are revealed in the data. Base pressure values were compared with measurements from stationary pressure gauges and with predictions of a standard two-stage gun code. The agreement with the pressure gages was satisfactory. Code predictions did not account for the two acceleration stages. However, for the main acceleration episode, the predicted base pressure is in good agreement with the smoothed pressure computed from the PDV record. Both the gauge records and PDV contain short-time pressure spikes which are apparently real. Therefore, use of computed base pressure for projectile design may lead to failures if the projectile is vulnerable to pressure spikes.

Keywords: piezometric efficiency, acceleration, light-gas gun.
PACS: 07.60.Ly, 07.60.Vg

INTRODUCTION

Projectile design performance is usually characterized by its *piezometric efficiency* ε—defined as the ratio of peak to average acceleration during the launch [1]. A more accurate estimate of the piezometric efficiency is likely to result in lower sabot mass and less need of expensive test shots to verify performance. A full understanding of the operation of the two-stage Light-Gas gun [2] at hypervelocities range will enable an increase in mass or velocity of the projectile. This is desirable since it reduces the degree of scaling (proportional to the cube root of mass) to reach the actual design parameters.

The Institute for Advanced Technology (IAT) recently analyzed [3] ε for past shots on IAT's high-velocity light-gas gun (LGG) having high-speed impacts (3.5 km/s < V_i < 5 km/s) and package mass 100 g < M < 200 g.

In that work, ε was estimated by scaling the ratio of peak gage pressure P_g measured at a position about a foot downrange of the acceleration reservoir (AR) in the $d = 10.93$ m barrel: $a_{peak} = P_g \pi r^2/M$ (where $r = 19$ mm bore radius, and M = launch package mass). The optimum acceleration constant that could be achieved during the launch $\langle a \rangle = v_i^2/(2d)$ was usually estimated from impact velocity v_i measurements derived timings and projectile positions determined from x-ray photographs of the projectile at two precise locations before impact. IAT found that these estimated piezoefficiencies $\langle\varepsilon\rangle$ bifurcated into two groups—with older experiments resulting in $\langle\varepsilon\rangle$ ranging 2.7–3.7—while most of the more recent shots resulted in $\langle\varepsilon\rangle$ ranging 5.5–6.5. The

This article is copyrighted as indicated in the article. Reuse of AIP content is subject to the terms at: http://scitation.aip.org/termsconditions. Downloaded to IP: 128.83.205.78 On: Mon, 23 Mar 2015 21:43:31

results suggested there was a change in pressure transducers, and it seemed likely that the more recent transducer has been giving values of pressure that are consistently too high.

To further test that hypothesis and effectively calibrate, IAT conducted experiments on the LGG, and applied high-resolution photonic Doppler velocimetry (PDV) [4,5] analysis to those experiments. Of these (Shot# 1114), a 200.5 g slug was launched in near-vacuum barrel (10 torr), impacting the target. In that experiment, unlike the otherwise universal procedure, the projectile was placed just downrange of the first barrel transducer, so that the measured gage pressure would, in principle, be the same as the computed base pressure at shot start. In this paper, this shot is further analyzed, comparing pressure gauges and the new PDV technique for obtaining projectile velocity history on a two-stage launcher. Gun code accuracy is also discussed.

MEASURED AND GUN CODE MODELED PRESSURES

TABLE I. Nomenclature

P_g	Measured pressure at launch tube breech
P_b	Code predicted base pressure
P_{AR}	Code predicted value of P_g
P_{PDV}	Pressure computed from measured in-bore PDV velocity
$P_{\mathbf{x}\text{-Max}}$	Maximum of respective pressure $P_{\mathbf{x}}$

In Fig. 1, IAT compares gun-code predicted pressures at the muzzle $P_{Muzzle}(T)$; in the acceleration reservoir $P_{AR}(T)$; and at the base of the projectile $P_B(T)$ as a function of time with gage pressure $P_g(T)$ measured one foot down-range of the AR for Shot# 1114. The measured and predicted time axes were synchronized by respective distinctive characteristics at the time of muzzle exit ($T = 0$). Like most of the prior shots analyzed in [3], the gun-code-predicted impact velocity was relatively close to that measured by both standard x-ray analyses and the newly acquired PDV analyses. The predicted $P_{AR\text{-Max}}$ (21 ksi) is a bit lower than that measured $P_{g\text{-Max}}$ (25 ksi). And like the earlier shots, the predicted peak base pressure $P_{b\text{-Max}}$ is 14.6 ksi and is significantly lower than $P_{g\text{-Max}}$. The piezoefficiency for Shot# 1114 calculated from the gun code model is <ε> = 1.16 while <ε> estimated with measured peak P_g is 2.72. Even though $P_g(t)$, $P_B(t)$, and $P_{AR}(t)$ for Shot# 1114 each match a distinctive feature of the base pressure P_{PDV} determined from the highly accurate PDV analyses, each have significantly different features.

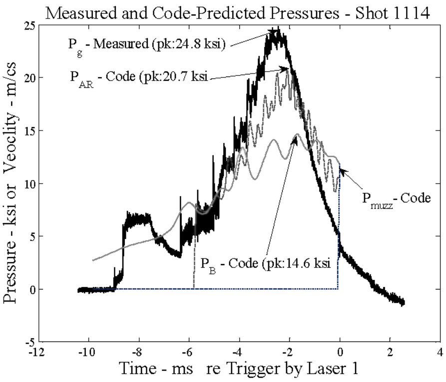

Figure 1. Comparison of the measured gage pressure P_g near the AR with code-predicted pressures: in the AR P_{AR}; at the projectile base P_B; and at the muzzle P_{muzz}.

Figure 2 shows the PDV velocity V and P_{PDV}, together with the gun-predicted pressures P_{AR} and P_B and gage pressure measurements P_g as a function of time T, axial position X, and velocity V. In contrast with the code predictions, the low-frequency features of $P_{PDV}(T)$ and $P_g(T)$ show two distinct acceleration stages during the launch. Although the specific times are different for the stationary (P_g) and dynamic (P_{PDV}) measurements, they track fairly well early in the launch. There is a sharp increase for both at T =-8.5 ms, a leveling off to 7 ksi for ~1 ms, a sudden decrease to 4 ksi for another 2 ms, and then a sharp rise again at P_g(-6 ms) and P_{PDV}(-5.5 ms).

Later in time, the pressure gage does a poorer job measuring the local acceleration behavior of the projectile, and $P_g(T)$ diverges from $P_{PDV}(T)$. This is consistent with the increasing displacement with time between the fixed gage location and the moving projectile's leading edge. Although the specific times are different for the stationary and moving measurements P_g and P_{PDV}, they track

This article is copyrighted as indicated in the article. Reuse of AIP content is subject to the terms at: http://scitation.aip.org/termsconditions. Downloaded to IP: 128.83.205.78 On: Mon, 23 Mar 2015 21:43:31

fairly well early in the launch. Later in time they diverge because P_g is measured at a fixed point in the gun while P_{PDV} is tracking the moving projectile.

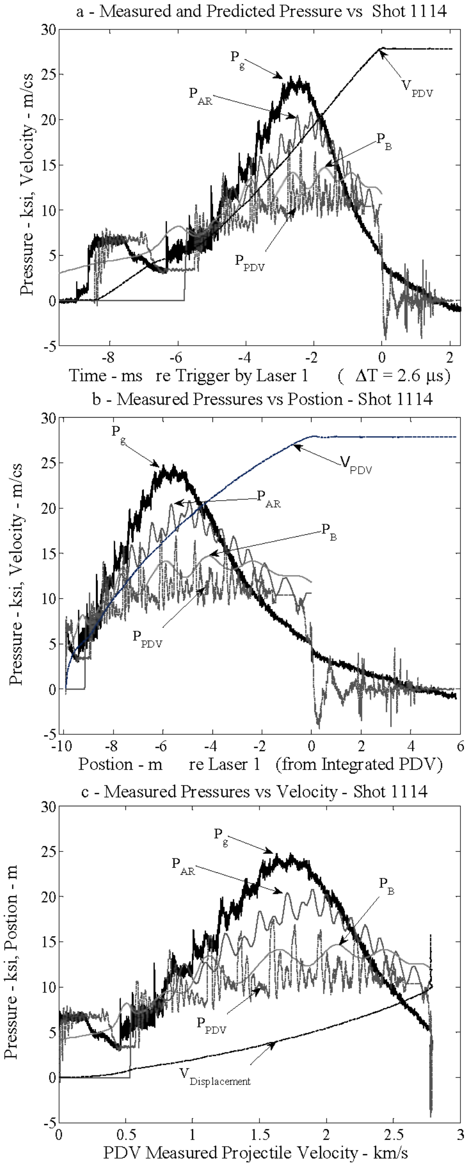

Figure 2. Velocity and acceleration from PDV, pressure from AR gages and gun-codes versus a-time, b-position (integrated from PDV velocity), and c-PDV velocity.

The code predictions do not show the two acceleration stages. We note that the code used to predict pressure P_B is somewhat old, and has lower frequency bandwidth than either of the measurements, P_g or P_{PDV}. However, the low frequency component (<1 kHz) of P_B and P_{PDV} are in reasonable agreement. Note that at later time, the gun-code predicted base pressure, $P_B(T)$, correlates better with $P_{PDV}(T)$ than either the measured $P_g(T)$ or the predicted $P_{AR}(T)$ - which is consistent with the local behavior of these quantities.

The high-frequency, spiky behavior of $P_g(T)$ and $P_{PDV}(T)$ is also of interest, and IAT believes neither is the result of artifacts. Rather, their origin is most likely due to reflections of the shock structure in the hydrogen gas - between the face of the driving piston in the 1st stage of the LGG and the trailing edge of the projectile in the second stage.

The pressure gage has a 100 kHz bandwidth, and data was averaged over 10-μs intervals. Similar, sharp narrow pulses are visible in $P_{PDV}(T)$—which are low-pass filtered with central-moving-average of $mav = 20$ adjacent samples, resulting in an effective time average $\Delta T = 65$ ms. Central moving average calculations were also analyzed using $mav = 5$, 10, and 50 adjacent samples. Although the height and breadth of the pulses depended on mav as expected, there was no such dependence on the location of times of the corresponding peaks. Therefore, IAT believes these are accurate features of the pressure rather than the result of numerical artifacts.

CONCLUSIONS

Code predictions did not account for the two acceleration stages of this shot. Although the gage-pressure measurements characterized both stages and accurately characterized the base pressure at the earliest part of the launch, its stationary character prevented it from accurately modeling the base pressure later, when it reached its peak.

ACKNOWLEDGEMENTS

The research reported in this document was performed in connection with contract number

This article is copyrighted as indicated in the article. Reuse of AIP content is subject to the terms at: http://scitation.aip.org/termsconditions. Downloaded to IP: 128.83.205.78 On: Mon, 23 Mar 2015 21:43:31

W911QX-07-D-0002 with the US Army Research Laboratory.

REFERENCES

[1] Donald E. Carlucci, Sidney S. Jacobson "Ballistics: Theory and Design of Guns and Ammunition," CRC Press, 2007, p.95.

[2] A.C. Charters, Development of the high velocity gas dynamics guns, International Journal of Impact Engineering 5 (1987) 181–203.

[3] S. Bless and S. Levinson, "Hypervelocity Impact into Geologic Targets—Experiment Design," IAT.R 0562.

[4] O. T. Strand, D. R. Goosman, C. Martinez, T. L. Whitworth, and W. W. Kuhlow, "Compact system for high-speed velocimetry using heterodyne techniques," *Rev. Sci. Intru.*, **77**, 2006.

[5] S. Levinson, S. Satapathy, "High-Resolution Projectile Velocity and Acceleration Measurement using Photonic Doppler Velocimetry," 16th APS Topical Conference on Shock Compression of Condensed Matter, June 28–July 3 2009; Nashville, Tennessee.

This article is copyrighted as indicated in the article. Reuse of AIP content is subject to the terms at: http://scitation.aip.org/termsconditions. Downloaded to IP: 128.83.205.78 On: Mon, 23 Mar 2015 21:43:31